




Surgical Strategies for Eyelid Defect Reconstruction: A Review on Principles and Techniques

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ABSTRACT

Reconstruction of eyelid defects, especially the posterior lamella, remains challenging because of its anatomical complexity, functional considerations, and aesthetic concerns. The goals of eyelid reconstruction include restoring eyelid structure and function and achieving an aesthetically acceptable appearance. An in-depth understanding of the complex eyelid anatomy and several reconstructive principles are mandatory to achieve these goals. Currently,

there are multiple surgical treatment options for eyelid reconstruction, including different flaps, grafts, and combinations of them. This comprehensive review outlines the principles of reconstruction and discusses the indications, advantages, and disadvantages of currently available surgical techniques. We also propose our clinical thinking for solving specific clinical questions in eyelid reconstruction and offer perspectives on new potential methodologies in the future.

Keywords: Anterior lamella; Eyelid defect; Eyelid reconstruction; Periocular reconstruction; Posterior lamella; Tarsus

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Key Summary Points

The goals of eyelid reconstruction include restoring eyelid structures and functions and achieving a cosmetically acceptable appearance with minimal surgical morbidity, which present a great challenge for surgeons

Making accurate etiological, functional, and anatomical/pathological diagnoses for the defects is critical for designing a plan for eyelid reconstruction

For optimal outcomes, the reconstructive strategy should be well planned based on the reconstructive ladder principles and defect characteristics, including defect thickness, size, and location

Due to the limitations of current surgical techniques and the rapid development of tissue engineering, the methodology of eyelid reconstruction, especially posterior lamella reconstruction, will transform from a replacement strategy to a regenerative strategy

INTRODUCTION

Reconstruction of eyelid defects caused by tumors, trauma, burns, and congenital factors remains a significant challenge in plastic and reconstructive surgery due to its anatomical complexity, functional considerations, and aesthetic concerns. Although numerous techniques have been described in the literature over the past decades, current clinically available techniques for eyelid reconstruction are essentially a replacement strategy [1]. Specifically, the first step is to identify whether the defect involves the anterior lamellar, the posterior lamellar, or both. Then, corresponding substitutes are used to replace the missing layers. The replacements for the anterior lamella mainly include skin grafts and local random

flaps, while those for the posterior lamella mainly include free autografts and tissue flaps. Here, we summarize the general principles and review current surgical techniques for eyelid defect reconstruction. All data presented in this article were gathered following approval from the local research ethics committee.

SURGICAL ANATOMY OF THE EYELIDS

An in-depth understanding of eyelid anatomy is essential for surgical planning and preventing complications. The eyelids are essentially bilamellar structures comprising the anterior and posterior lamella (Fig. 1). The anterior lamella includes the skin and orbicularis muscle. Eyelid skin is the thinnest of all body skin and lacks subcutaneous fat, which has high elasticity and facilitates motility. The orbicularis muscle, consisting of pretarsal, preseptal, and orbital subunits, is responsible for eyelid closure. The posterior lamella comprises the tarsal plate and palpebral conjunctiva. The tarsus is a unique transitional tissue that features both dense fibrous connective tissue and cartilage tissue, which consists mainly of fibroblasts surrounded by extracellular matrix (ECM) and abundant meibomian glands. The tarsus is approximately 25 mm long and 1 mm thick, and the tarsal height varies from 8 to 12 mm in the upper eyelid to 4–5 mm in the lower eyelid [2]. The conjunctiva comprises overlying stratified and nonkeratinized epithelium with interspersed, secretory active goblet cells resting on a vascularized basement membrane. It can spontaneously re-epithelialize upon injury. The palpebral conjunctiva connects tightly to the tarsus and provides additional lubrication for the cornea and globe that facilitates eyeball movement and reduces friction.

The primary supports of the eyelids are the medial and lateral canthal tendons, which attach to the tarsi and provide anterior-posterior stability to the eyelids as the tarsoligamentous sling. The medial canthus attaches to the anterior and posterior lacrimal crest. The lateral canthus attaches posterior to the lateral orbital rim at Whitnall's tubercle. Vertical stabilization

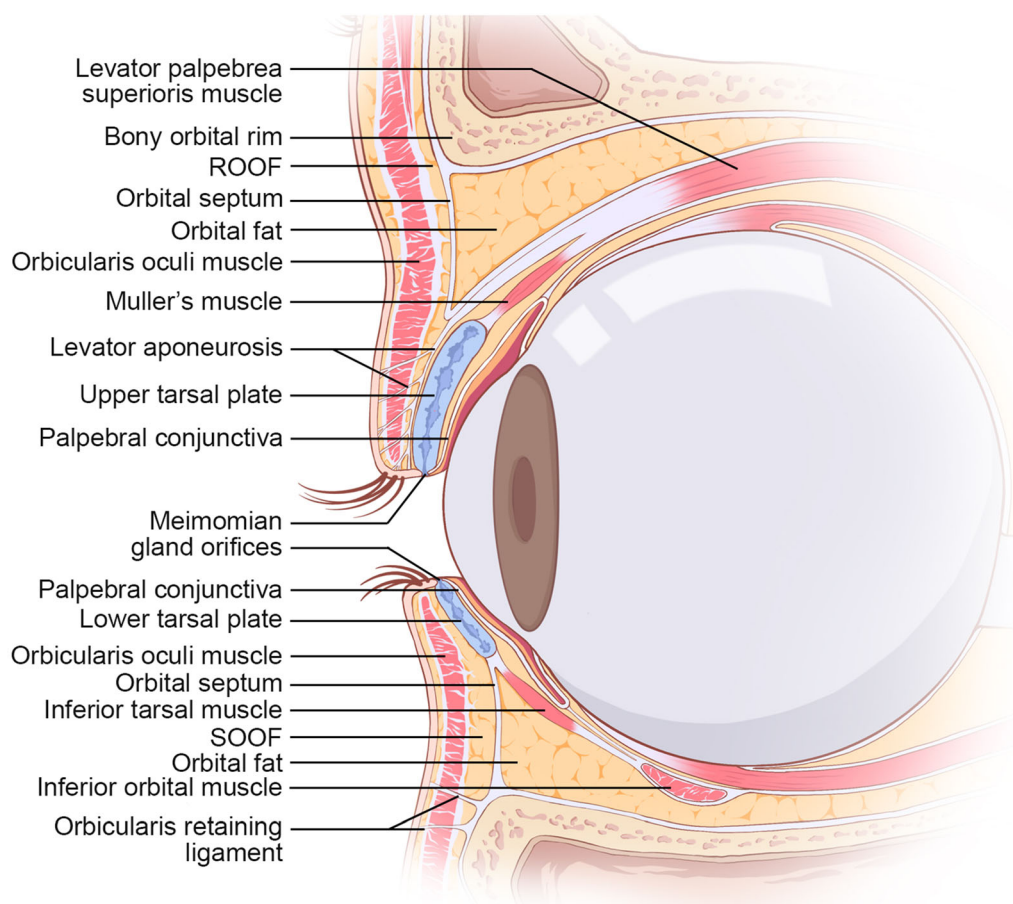


Fig. 1 Anatomical structures of upper and lower eyelids. *ROOF* retro-orbicularis oculi fat, *SOOF* sub-orbicularis oculi fat

is provided to the upper eyelid by the levator aponeurosis (attaches to the superior tarsus) and to the lower eyelid by the retractors (attaches to the superior tarsus) (Fig. 2).

GENERAL RECONSTRUCTIVE PRINCIPLES

The goals of eyelid reconstruction include restoring eyelid structures and functions, achieving a cosmetically acceptable appearance with minimal surgical morbidity, and, more importantly, maintaining ocular surface homeostasis to prevent visual impairment [3, 4]. To achieve these goals, the reconstructive strategy should be well planned based on reconstructive ladder principles and defect characteristics. According to the reconstructive ladder principles, the surgeon should take the simplest

approaches and use “like” tissues to restore both function and cosmetic appearance as much as possible. Typically, an ideal method for eyelid reconstruction should have the following characteristics: (1) good contact without irritation to the bulbar conjunctiva and cornea; (2) supportability, particularly in the lower eyelids; (3) applicability to various types of defects; (4) easy performance; (5) minimal damage to the donor site [5].

Furthermore, reconstruction plans should be designed according to the defect characteristics, including the defect thickness, size, and location. First, the thickness of the defect determines which structure needs to be reconstructed. Partial-thickness defects only involve the anterior lamellar. Isolated anterior lamellar defects may need not only skin coverage but also orbicularis muscle reconstruction. The defects

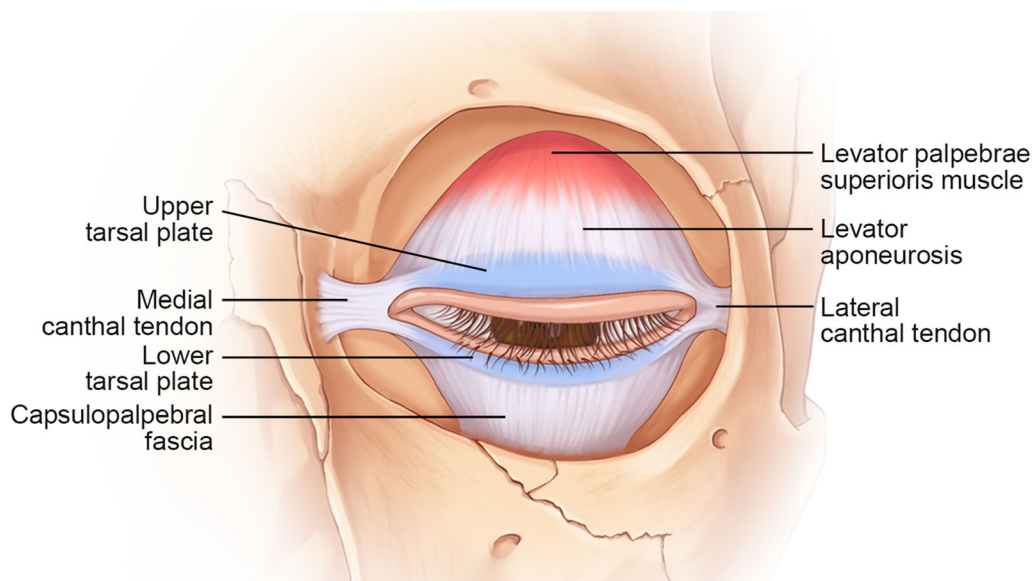


Fig. 2 Supporting system of upper and lower eyelids

involving the posterior lamella are usually full-thickness defects, which require reconstruction of the two lamellae separately, and at least one lamella should provide blood supply. Second, the size of the defect determines how much tissue is needed. Defects that are $< 25\%$ of the lid can be closed primarily depending on the skin laxity. However, defects that are $> 20\text{--}30\%$ of the eyelid usually require free tissue grafts or flaps for reconstruction [6]. For full-length eyelid defects with complete tarsus loss, combinational techniques are often considered. Third, the location of the defect may require surgeons to take some special structures into consideration. For instance, surgeons repairing defects in the medial canthal area should carefully evaluate the function of the lacrimal system. Full mobility is crucial for the upper eyelid but is less important for the lower eyelid. However, maintenance of a static position that will contact the upper eyelid upon closure is necessary.

ANTERIOR LAMELLAR DEFECTS

Small ($< 25\%$ of the eyelid) and superficial anterior lamellar defects are often closed directly or left alone for secondary healing. For large defects involving the skin and potentially

the underlying orbicularis muscle, skin grafts or flaps are often preferred. The reconstruction of anterior lamellar defects should (1) use thin and pliable skin with optimal color and texture matching, (2) place incisions in natural lid lines, and (3) distribute horizontal tension at the lid margins and vertical tension at the lateral or medial canthal regions. Table 1 shows a summary of the techniques for anterior lamellar reconstruction.

Full-Thickness Skin Graft (FTSG)

FTSG is suitable for simple anterior lamellar defects with a healthy orbicularis base [7, 8] or for use in combination with vascularized posterior lamellar replacements for bilamellar defects [9, 10]. Aesthetically, skin tissues from the ipsilateral or contralateral eyelid, retroauricular, inner brachial, and supraclavicular areas that provide similar color, thickness, and texture are considered ideal donor sites for the periocular region [11]. Hypertrophic scarring is the most common complication and can be reversed by massage, steroid ointment, and silicone gel application [12].

Table 1 Techniques for anterior lamellar defect reconstruction

Technique	Indications	Advantages	Disadvantages
<i>Grafts</i>			
FTSG	Simple skin defect with healthy orbicularis base	Ease; minor donor site morbidity; no dimension limitation	Relatively high rates of graft contraction and hypertrophy
<i>Local random flap</i>			
V–Y advancement flap	Deep, small defects located along the nasal sidewall	Ease; “like for like” reconstruction	Requirement of great skin laxity; vertically scar across the skin tension line; high vertical tension that may cause entropion
Rhomboid transitional flap	Mild medial and lateral canthal defects	Ease; minor donor site morbidity; “like for like” reconstruction	Requirement of great skin laxity
Mustarde cheek rotational flap	Deep, vertical defects of the entire lower eyelid	Single-stage procedure; large flap size; reliable blood supply	Relatively high thickness for eyelid; invasive procedure; risk of facial nerve lesion
Tripier flap	Entire lower eyelid defects	Use of excess upper eyelid orbicularis and skin; long flap length; less bulky	Limited vertical size, possible unreliability of the distal part of the unipedicled flap
Fricke flap	Entire upper and lower eyelid, lateral canthal defects	Long flap length	Two-stage procedure; excessive thickness for eyelid; limited vertical size; risk of frontal branch lesion; possible eyebrow elevation; possible unreliability of the distal part of the flap
<i>Axial flap</i>			
Frontal flap based on STA	Entire upper and lower eyelid, and lateral canthal defects	No dimension limitation; possibility of dissection into island flap	Two-stage procedure; necessity of good surgical skills; skin grafting required to repair donor site; possible eyebrow elevation; unreliable venous outflow
Forehead flap based on supratrochlear artery	Entire upper and lower eyelid, and medial canthal defects	No dimension limitation, reliable blood supply	Two-stage procedure; necessity of good surgical skills; excessive thickness for upper eyelid
Nasolabial flap based on angular artery	Entire upper and lower eyelid, and medial canthal defects	No dimension limitation, excellent color and texture matching; minor donor site morbidity; provision of eyelid-cheek transition	Potentially compromised blood supply; risk of ectropion

Local Random Flaps

Local random flaps have shown superior functional and aesthetic outcomes compared with FTSGs because of superior color and texture matching, a better blood supply, and reduced scarring. According to the repositioning method of the flaps, local random flaps can be categorized as advancement and rotational flaps. Advancement flaps are suitable for small to medium defects but unfeasible for defects greater than 80% of the upper eyelid because of the limited excess skin. Compared with advancement flaps, rotational flaps can be designed contiguous to the defect or at some distance away and are therefore more suitable for large defects of up to the whole length of the eyelid.

V–Y Advancement Flap

The V–Y advancement flap is a subcutaneous island pedicle flap and is commonly used to reconstruct anterior lamellar defects located along the nasal sidewall extending into the medial canthus and even the entire lower eyelid [13–15]. This flap is also modified to repair upper eyelid defects [16]. Typically, the V–Y advancement flap is designed as a triangular island positioned parallel to or within the nasolabial fold with the width of the flap equal to the width of the defect. The flap is then advanced vertically to the defect area based on the subcutaneous muscular pedicle. The V–Y flap requires less dissection and operation time, but advancement of the flap results in a vertical scar across the relaxed skin tension line, which can cause postoperative ectropion, especially on the lower eyelid. This flap has been modified to follow a horizontal orientation to minimize the risk of postoperative lower lid mispositioning [17–19].

Rhomboid Rotational Flap

The rhomboid rotational flap offers a versatile approach to the repair of periocular defects, particularly for medial and lateral canthal defects [20]. The classic rhomboid flap is designed in a rhombus shape with internal angles of 60° or 120°. The flap is then

repositioned for defect repair, and the final closures of these flaps can be hidden in the glabellar folds, eyelid crease, or medial or lateral canthal angles. The design of this flap should follow the principles of horizontal tension distribution at the lid margins and vertical tension at the lateral and medial canthal regions to avoid canthal height distortion [21]. However, most periocular defects are circular or ovoid, and these defects can be conceptualized in a rhomboid shape and treated with modified rhomboid flaps [22].

Mustarde Cheek Rotational Flap

The Mustarde cheek rotational flap recruits skin tissue from the lateral cheek and preauricular area and is suitable for repairing deep vertical defects involving up to the entire anterior lamella of the lower eyelid in a single-stage procedure, especially if the vertical dimension of the defect is greater than the horizontal dimension (Fig. 3). Appropriate techniques to anchor or suspend the cheek flap to the lateral canthus or periosteum [23] or to sling it with a dermis-fat flap [24] are also necessary. The Mustarde flap is a reliable and versatile technique with a large donor area and sufficient blood supply [25, 26]. However, the cheek skin is relatively thick for the eyelid. In addition, it is a comparatively invasive procedure and may cause facial nerve injury.

Tripier Orbicularis Myocutaneous Flap

The Tripier orbicularis myocutaneous flap is harvested from the upper eyelid and transposed to the lower lid as a unipedicled or bipedicled flap. A unipedicled flap can be used to repair defects involving 1/3–1/2 of the lower eyelid (Fig. 4), and a bipedicled flap can be used for total lower eyelid defects [27, 28]. This flap has been modified to an island Tripier flap for aesthetic reconstruction of subtotal defects away from the lateral canthus and a reverse Tripier flap for upper eyelid reconstruction [29]. This procedure uses the excess upper eyelid orbicularis and skin but has a limited size, particularly in the vertical dimension [30].

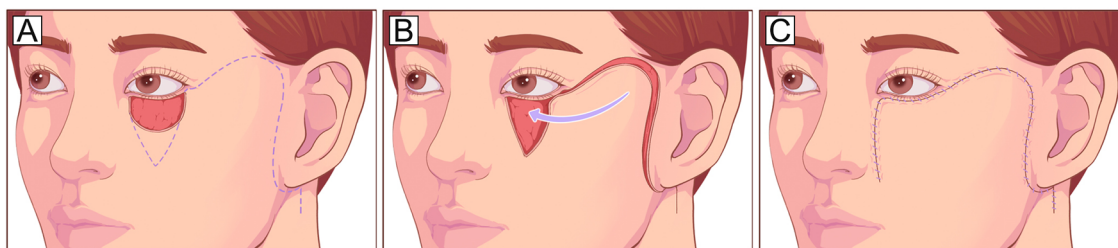


Fig. 3 Mustarde cheek rotational flap. **A** Large vertical anterior lamella defect of the lower eyelid and planned incision design (dotted line). The incision runs laterally from the level of the lower eyelid and lateral canthus, superiorly into the temporal skin, and finally inferiorly toward the preauricular areas. **B, C** The flap is undermined in the subcutaneous or SMAS plane and

rotated medially to cover the defect. To reduce the tension in the lid-cheek margin and avoid postoperative ectropion, the flap should be designed along the natural curve of the lower eyelid with a high takeoff from the lateral canthus to the temple before curving inferiorly. SMAS, superficial muscular aponeurotic system

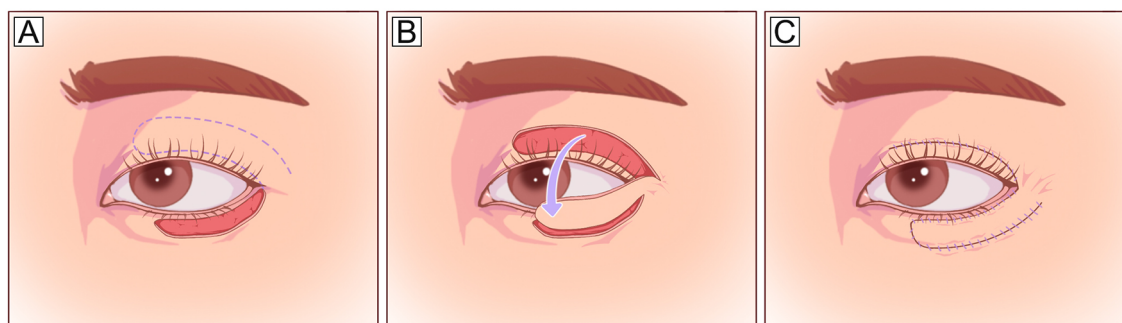


Fig. 4 Tripier orbicularis myocutaneous flap (unipedicled). **A** Anterior lamellar defect involving 2/3 of the lower eyelid and planned incision design on the upper eyelid (dotted line). **B** The flap is elevated under the orbicularis

muscle plane and pedicled on the orbicularis muscle laterally. **C** The flap is transposed inferiorly to cover the defect

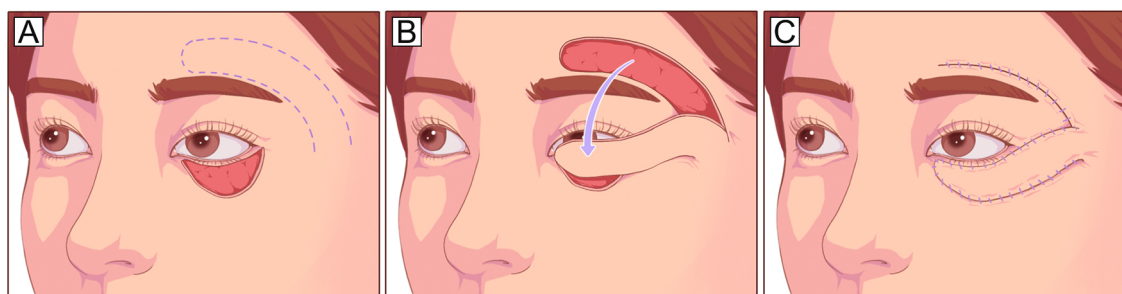


Fig. 5 Fricke forehead flap. **A** Large lateral lower eyelid defect with long horizontal length and short vertical height and planned incision design on the forehead. The flap design should obey a width-to-length ratio of 1:2 to ensure

blood supply to the flap tip. **B, C** The flap is elevated as a random cutaneous flap and rotated inferiorly to cover the defect

Fricke Forehead/Cheek Flap

The Fricke forehead flap is a temporally based unipedicled transposition flap that can be used in the reconstruction of large lower and upper eyelid defects and lateral canthal defects [31] (Fig. 5). It is particularly useful when the defect involves the entire lower eyelid but with a relatively short height [32]. However, this two-stage operation may injure the frontal branch of the facial nerve and often result in eyebrow level elevation, upper eyelid malposition, and even lagophthalmos, which requires additional tissue recruitment for correction to prevent exposure keratitis [33]. A modification of this flap is harvesting the flap from the cheek instead of the forehead (Fricke cheek flap, Fig. 6), which offers a larger amount of available tissue and avoids the elevation of the eyebrow [34].

Axial Flaps

Axial flaps can be designed much larger than random flaps. Thus, they are more suitable for the reconstruction of large eyelid defects. However, these techniques require superb surgical skills for dissecting the perforators to avoid flap congestion and subsequent sequelae at the donor site [35, 36].

Frontal Flap Based on the Frontal Branch of the Superficial Temporal Artery (FBSTA)

The FBSTA-based frontal flap is similar to the Fricke flap but vascularized by a perforator of the FBSTA, which allows a significant supply of cutaneous tissue for covering defects of the

upper or lower eyelid and the lateral canthal area [37, 38]. This flap can be dissected into an island flap based on a perforator [38, 39], which allows elevation of a thin flap for eyelid reconstruction within a single surgery. A bilobed island flap, which is composed of two FBSTA perforator-based island flaps or a tulip-shaped flap, has been used to reconstruct lateral canthus defects involving both the upper and lower eyelids and even the eyebrows [40].

Forehead Flap Based on the Supratrochlear Artery (STA)

The STA-based forehead flap is a workhorse for the reconstruction of intermediate-sized peri-orbital defects [41], especially those associated with nasal defects. This flap closely matches the eyelid pigmentation but is too bulky for periorcular reconstruction. Anatomically, the STA emerges from the ophthalmic artery and travels superomedially under the orbicularis oculi muscle. The STA provides a consistent cutaneous branch in a position 1.18 ± 0.36 cm distal to the supraorbital rim [42], which allows the forehead flap to be trimmed as an ultrathin flap from 2 cm superior to the orbit and modified into an island flap [43] or tunneled flap [44] to conform to the complex landscape around the orbit.

Nasolabial Flap Based on the Angular Artery

The angular artery-based nasolabial flap is well suited for repairing moderate to large defects of the lower eyelid and medial canthal area [45]. The angular artery mainly originates from either the ophthalmic artery or the infraorbital

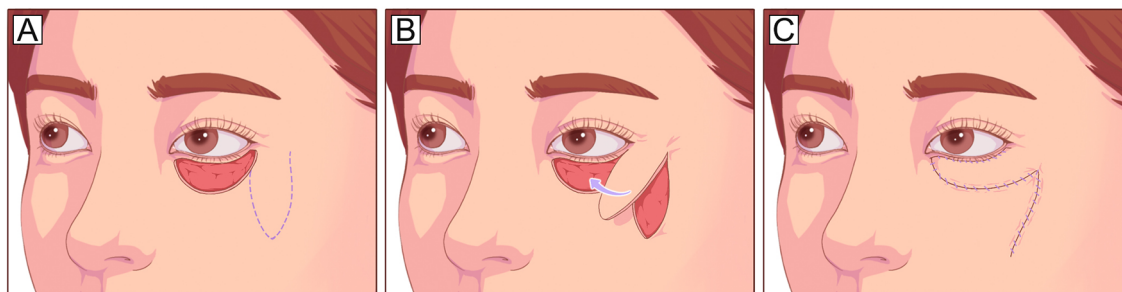


Fig. 6 Fricke cheek flap. **A** Large anterior lamella defect involving the entire length of the lower eyelid and planned incision design on the cheek. **B, C** The flap is undermined in the orbicularis muscle plane and rotated superiorly to cover the defect

artery and travels along the nasolabial fold [46], which allows the flap to be dissected as a superiorly pedicled nasolabial flap. The advantages of this flap include (1) easy flap dissection; (2) excellent color and texture matching; (3) provision of an eyelid-cheek transition; (4) minor donor morbidity [47, 48]. However, the potentials for compromised flap blood supply, ectropion, and lagophthalmos are the main limitations of this technique [49].

POSTERIOR LAMELLAR DEFECTS AND FULL-THICKNESS DEFECTS

Reconstruction of posterior lamellar defects requires a layer of dense tissue with similar mechanical strength to the native tarsus to provide primary support to the eyelid and a layer of soft tissue with a similar structure to the native conjunctiva to provide additional lubrication to the globe. Direct closure is preferable for defects of < 25% of the eyelid length. When the defect involves 25–50% of the eyelid, the use of local tarsoconjunctival flaps or cantholysis can achieve primary closure. When the defects involve up to 50% of the eyelid, free autografts, tissue flaps, or combinational techniques are often needed. When the anterior lamella provides sufficient vascular support, posterior lamellar defects can be repaired by free autografts. In contrast to free autografts, tissue flaps repair posterior lamellar defects in the form of vascularized tissues, which allows for replacement of the anterior lamella with an FTSG, local flaps, or switch flaps in full-thickness eyelid defects. Table 2 shows a summary of techniques for posterior lamella and full-thickness reconstruction.

Free Autografts

Tarsoconjunctival or Tarsal Graft

The tarsoconjunctival grafts taken from healthy eyelids are the gold standard tissue for posterior lamellar reconstruction [50] and have been used to repair defects of up to 75% of the eyelid length [51, 52]. Typically, the size of the donor tarsoconjunctival graft ranges from 4 to 5 mm

vertically and 8–16 mm horizontally, and preservation of at least 4 mm of the tarsus is recommended to avoid complications. Tarsal grafts can be regarded as tarsoconjunctival grafts without the conjunctival lining. Free tarsoconjunctival grafts or tarsal grafts are often used in combination with other tissue flaps to provide a blood supply for the grafts in full-thickness defects [51, 53, 54]. When free tarsal grafts are used for posterior lamellar reconstruction, the conjunctival lining is often absent, leaving it to be gradually re-epithelialized from the marginal conjunctiva. The main limitations are donor eyelid morbidity, small graft size, and possible corneal irritation requiring a mucus membrane graft to protect the ocular surface [55].

Tarsomarginal Graft

The tarsomarginal grafts are composite grafts consisting of tarsus, conjunctiva, eyelashes, and eyelid margins (Fig. 7). Typically, one-quarter or occasionally even one-third of the donor eyelid can be harvested with primary closure, and sequential grafts can be used for larger defects involving 1/4–3/4 of the upper or lower eyelid [56]. Tarsomarginal grafts are ideal autografts for posterior lamellar reconstruction because they retain the normal physiological structures of the eyelid margin, although the eyelash survival rate varies greatly. Scar formation and eyelid retraction are the main complications, and revision surgery is occasionally required [56].

Hard Palatal Mucoperiosteal (HPM) Graft

The HPM grafts have both fibrous connective tissue and a mucosal surface that is histologically similar to the tarsoconjunctiva [57]. HPM grafts can provide good and lasting structural support to the eyelids, making them an optimal choice for repairing posterior lamellar defects [58, 59]. However, HPM is a tissue structured with keratinized stratified squamous epithelium, and orthokeratosis may persist for years following transplantation, which may irritate the cornea. Thus, the application of HPM grafts in upper eyelid reconstruction remains controversial, especially when the eyelid defect is

Table 2 Techniques for posterior lamella and full-thickness defect reconstruction

Reconstructive methods	Indications	Main advantages	Main disadvantages
<i>Free autografts</i>			
Tarsoconjunctival graft	Defects up to 75% of lower lid	“Like for like” reconstruction	Limited donor site; donor site morbidity; graft shrinkage
Tarsomarginal graft	Defects involving 1/4–3/4 of upper or lower eyelid	“Like for like” reconstruction; preservation of eyelash and eyelid margin; allows sequential grafting	Limited donor site; donor eyelid; risk of eyelid retraction
HPM graft	Defects involving 1/2 to total of upper or lower eyelid	Hidden donor site, tissue structure matching	Cornea irritation due to the keratinized epithelium; donor site morbidity; pain
Nasal chondromucosal graft	Defects involving 1/2 to total of upper or lower eyelid	No dimension limitation; a combination of cartilage and mucosa, hidden donor site	Donor site morbidity; risk of perforation and hemorrhage
Auricular cartilage graft	Defects involving 1/2 to total of upper or lower eyelid	No dimension limitation; easy to harvest, minor donor site morbidity; low contraction rate	Cornea irritation due to lack of lining tissue, stiffness
<i>Tissue flaps</i>			
Local tarsoconjunctiva flap	Upper and lower eyelid defects less than 60% of the horizontal eyelid length	“Like for like” reconstruction; single-stage procedure	Limited donor site
Hughes flap	Defect involving 1/2 to total of lower eyelid	“Like for like” reconstruction	Two-stage procedure; donor eyelid morbidity; longtime of vision occlusion
Reversed Hughes flap	Defect involving 1/2 to total of upper eyelid	“Like for like” reconstruction	Two-stage procedure; donor eyelid morbidity; longtime of vision occlusion
Cutler-Beard flap	Defect involving 1/2 to total of upper eyelid	“Like for like” reconstruction	Two-stage procedure; donor eyelid morbidity; longtime of vision occlusion; requirement of tarsal substitutes; risk of lower lid entropion
Tenzel flap	Full-thickness defects involving 1/2–2/3 of lower or upper eyelid margin	Full-thickness reconstruction; single-stage procedure; minor donor site morbidity; preservation of eyelid margin with eyelashes	Requirement of temporal skin laxity; requirement of posterior coverage

Table 2 continued

Reconstructive methods	Indications	Main advantages	Main disadvantages
Mustarde lower lid sharing flap	Full-thickness defects involving 30–60% of upper eyelid margin	Full-thickness reconstruction; preservation of eyelid margin with eyelashes	Two-stage procedure; risk of lower lid entropion

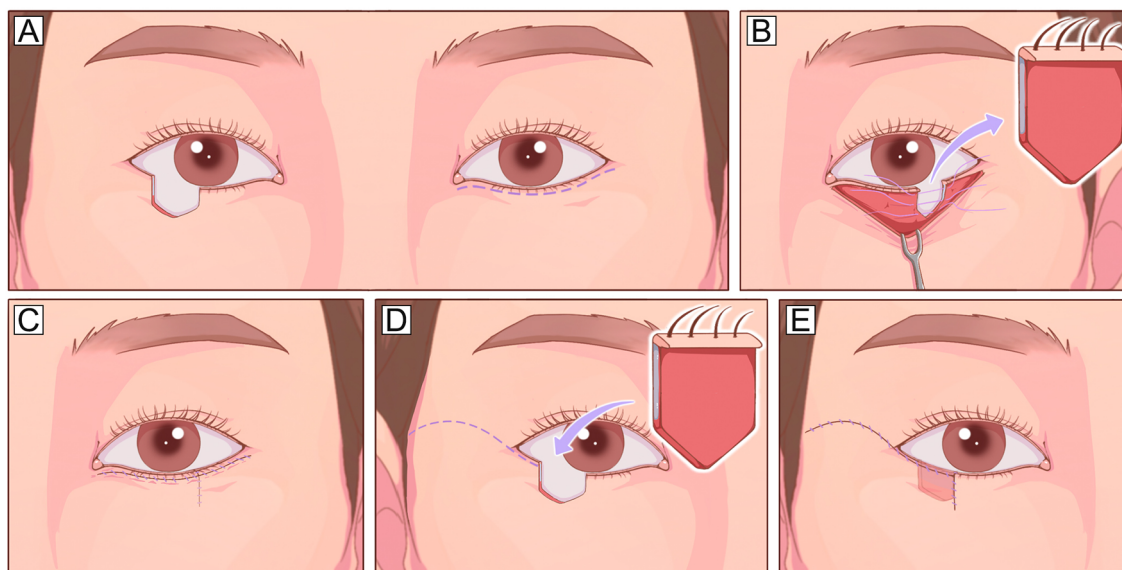


Fig. 7 Tarsomarginal graft. **A** A full-thickness defect with a half-length of the entire lower eyelid. **B** A planned incision is designed 2 mm inferior to the eyelid margin. **C** The myocutaneous flap is dissected to expose the posterior lamella, and a tarsomarginal graft with a length half of the defect is harvested. **D** The donor eyelid can be

closed with primary closure. **E, F** The full-thickness lower eyelid defect is reconstructed using two different techniques: the posterior lamella defect is repaired with the harvested tarsomarginal graft, and the anterior lamella defect is closed with a local Tenzel flap

adjacent to the middle part of the cornea [58]. In addition, the donor site of the HPM graft is typically left alone for secondary healing, which results in donor site discomfort, possible hemorrhage, and feeding difficulties.

Nasal Chondromucosal Graft

The nasal chondromucosal grafts harvested from the nasal septum [32, 60–62] or ala [63, 64] can offer both support and lining for replacing the tarsus and conjunctiva. The septal mucochondral graft tends to curl toward the mucosa-covered side after thinning of the cartilage,

which matches the shape of the tarsus and can provide good eyelid stability and aesthetic outcomes [65, 66]. The donor site of septal chondromucosal grafts is typically left with nasal packing for secondary healing, which may result in septal perforation and hemorrhage [67]. Harvesting chondromucosal grafts from the nasal ala can avoid these complications and yield good results [63].

Auricular Cartilage Graft

The auricular cartilage is elastic cartilage with a spherical surface, suitable flexibility, and

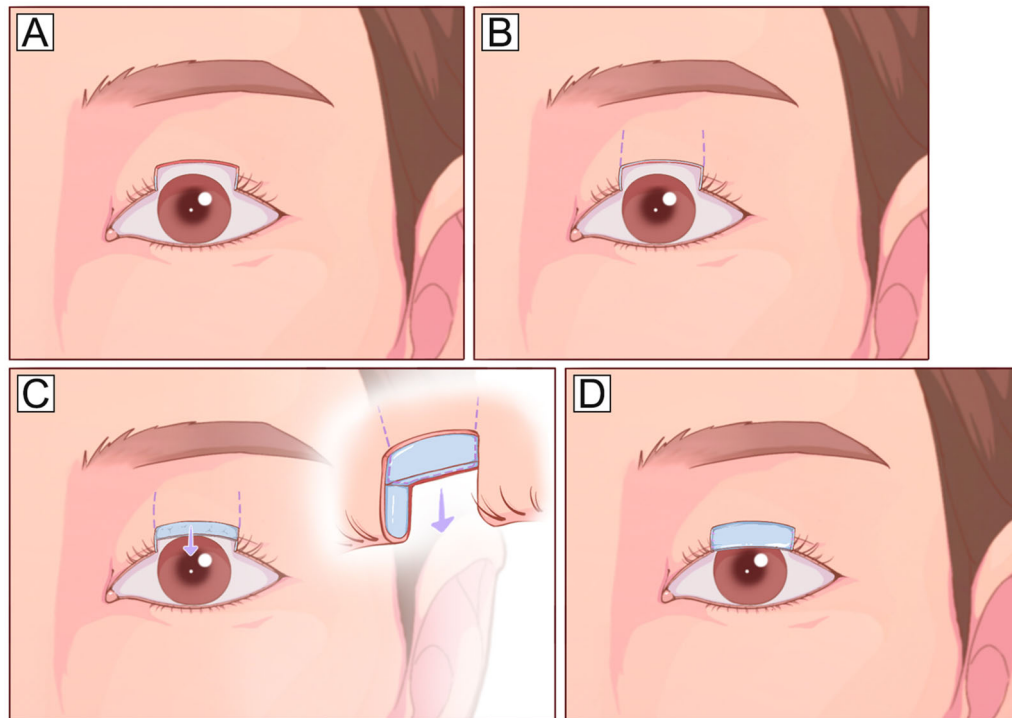


Fig. 8 Tarsalconjunctival advancement flap. **A** A full-thickness upper eyelid defect involving the center upper tarsus and eyelid margin. **B** Planned incision design on the upper eyelid. **C**, **D** The residual center tarsus is cut

vertically and mobilized on a conjunctival pedicle and advanced inferiorly to repair the posterior lamella part of the defect

appropriate physical strength [67]. Compared with other autografts, auricular cartilage is thin, relatively abundant, easy to harvest, and has minor donor site morbidity [68]. Reconstruction of eyelid defects with auricular cartilage grafts shows an aesthetic contour and sufficient support without obvious graft shrinkage or absorption, which prevents eyelid retraction and other complications [69–71]. However, these grafts lack an inner lining for conjunctival reconstruction, and irritation due to direct contact between the eyeball and the raw surface of the graft remains a concern [67]. Preserving the perichondrium or overlaying an oral mucosa graft may be beneficial for solving this problem [5].

Tissue Flaps

Local Tarsalconjunctival Flap

Posterior lamellar defects involving < 60% of the horizontal length can be repaired by using local tarsalconjunctival flaps according to the configuration of the defects. Central defects involving the inferior tarsus and eyelid margin are easily closed using a tarsalconjunctival advancement flap raised from the residual central superior tarsus [72] (Fig. 8). Medial or lateral defects can be repaired using a tarsalconjunctival sliding flap from adjacent eyelid tissue [73] (Fig. 9). Isolated defects involving the lateral canthus area of the lower eyelid can be repaired using a Hewes tarsalconjunctival flap transposed from the upper eyelid (Fig. 10). These techniques are relatively simple and make full use of the remaining tarsus without tissue transplantation but require a residual tarsus height of at

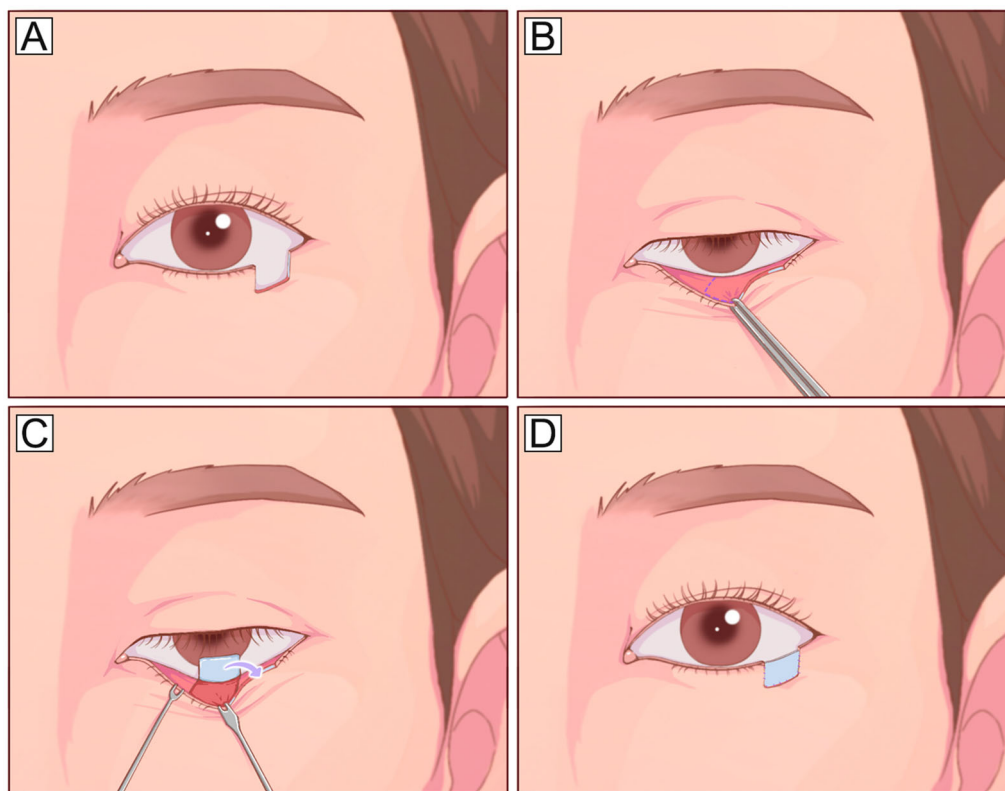


Fig. 9 Tarsconjunctival sliding flap. **A** A full-thickness defect involving the lateral lower eyelid and eyelid margins. **B** A tarsconjunctival flap is designed on the medial

residual eyelid. **C, D** The tarsconjunctival flap is dissected in the posterior lamella plane and slides laterally to fill the posterior lamella defect

least 3–4 mm to maintain the stability of the reconstructed eyelid.

Hughes Tarsconjunctival Flap

The Hughes tarsconjunctival flap involves a two-stage eyelid-sharing technique for repairing lower eyelid defects involving 50–100% of the eyelid margin [74–76]. This flap delivers a vascularized tarsconjunctival flap with a maximum height of 3–4 mm from the upper eyelid margin to the lower eyelid defect [77–79] (Fig. 11). The anterior lamella is typically reconstructed using an FTSG or local cutaneous or myocutaneous flap for full-thickness defects [80]. Following the same principles, a reverse Hughes flap, which transfers a pedicled tarsconjunctival flap from the lower eyelid to the posterior lamellar defect of the upper eyelid, has been used for large upper eyelid reconstruction [81, 82]. However, these eyelid-sharing

procedures lead to meibomian gland loss, lid margin abnormalities, exposure keratopathy [83], and dry eye symptoms [84, 85]. Furthermore, long-term vision occlusion also limits their application, especially in monocular patients [86]. Consequently, the classic Hughes technique is often modified to reduce postoperative complications and improve the blood supply of the flap [68, 74, 87, 88].

Cutler-Beard Flap

The Cutler-Beard flap involves a two-stage eyelid-sharing technique for repairing full-thickness upper eyelid defects involving up to 50% of the eyelid [89]. This flap uses a skin-muscle-conjunctiva flap from the lower eyelid to repair upper eyelid defects (Fig. 12). Similar to the Hughes tarsconjunctival flap, this flap also impairs vision and requires secondary flap division; unlike the Hughes flap, this flap is a

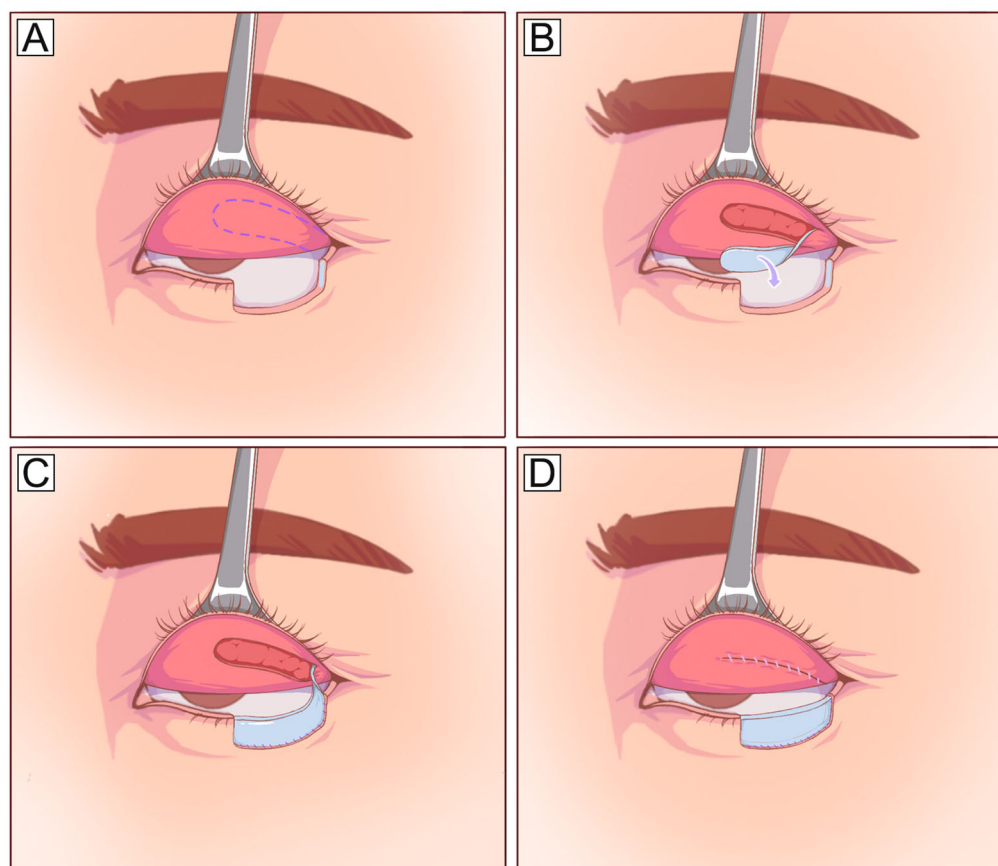


Fig. 10 Tarsconjunctival sharing flap. **A** A laterally located full-thickness defect involving half the length of the lower eyelid. **B** A tarsconjunctival flap is planned on the posterior lamella of the ipsilateral upper eyelid. **C**,

D The flap is elevated and transposed with a lateral pedicle on the upper eyelid to fill the posterior lamella defect on the lower eyelid

full-thickness flap containing skin, muscle, and conjunctiva. Due to the lack of tarsus within this flap, an additional tarsus substitute, such as free auricular cartilage [31, 90], contralateral tarsus, tarsconjunctiva [51, 91], or commercial dermal matrix [92], is required to reconstruct the upper eyelid tarsus to prevent postoperative retraction and entropion. Upper eyelid retraction and entropion are common complications of this technique [91].

Tenzel Semicircular Rotational Flap

The Tenzel semicircular flap has a good color match and minor donor site morbidity and can be used to cover defects involving 1/2–2/3 of the lower or upper eyelid in a single-stage procedure [93, 94]. The flap procedure elevates a

laterally or centrally based orbicularis myocutaneous flap initially in the suborbicular plane within the orbital rim and later along the subcutaneous plane beyond the orbital rim, and then the flap is rotated medially for primary closure of the defect (Fig. 13). The Tenzel flap is simple and efficient and can provide an uninterrupted full-thickness eyelid segment with a lash line [93, 95], but the flap is still not free from cicatricial ectropion.

Mustarde Lower Lid Sharing (Lid Switch) Flap

The Mustarde lid switch procedure transfers a full-thickness eyelid flap from the lower eyelid margin to repair an upper eyelid defect [96, 97]. It is well suited for full-thickness, shallow defects involving 30–60% of the upper eyelid,

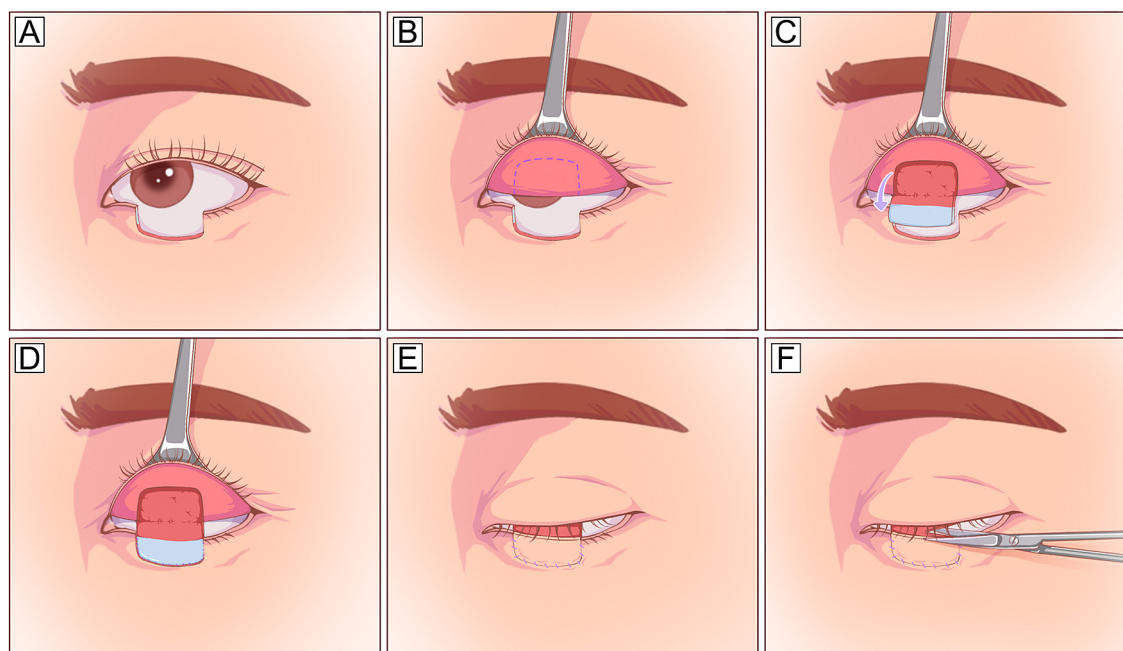


Fig. 11 Hughes tarsoconjunctival flap. **A** A full-thickness defect involving the center part of the lower eyelid and eyelid margin. **B** Planned incision design on the conjunctiva surface of the upper eyelid. The flap is designed 4–5 mm from the upper eyelid margin, leaving a strip of the tarsus for structure support. **C** The flap is dissected in

the posterior lamella plane and transposed inferiorly based on a superior conjunctiva pedicle. **D** The tarsoconjunctival part of the flap is advanced into the defect and sutured with the residual tarsus of the lower eyelid. **E** The anterior lamella defect is reconstructed with an FTSG. **F** The flap is separated after 2–4 weeks

especially for patients who wish to have intact lash restoration. The flap should have a vertical height of 4 mm and a defect length of 1/2–2/3 of the upper eyelid to incorporate the marginal arcade. The flap is typically divided after 2–4 weeks, and the donor site is then repaired via direct closure, lateral canthotomy, or local myocutaneous flaps (Fig. 14). If there is excess tension, lateral canthotomy and cantholysis should be performed to minimize the risk of ectropion. Compared with the classic Cutler-Beard flap, this technique provides greater eyelid stability and allows reconstruction of the lash margin.

Combinational Techniques

When defects involve two or more layers of eyelid structure, combinational techniques consisting of two or three tissue grafts/flaps are often used to restore the “layer-by-layer” structure of the eyelid. Among them, at least one

vascularized tissue/flap is required to provide blood supply for the other free grafts. The basic formula for this technique is one vascularized flap for anterior lamellar reconstruction in combination with one free graft for posterior lamellar replacement. The commonly used flaps are medially or laterally based orbicular myocutaneous flaps [98, 99] and frontal or forehead axial flaps [37, 100], and the commonly used posterior lamellar substitutes are HPM [37, 58], auricular cartilage [100], tarsal grafts [99], and acellular dermal matrixes (ADMs) [82]. In contrast, a vascularized flap for posterior lamellar reconstruction and a free autograft for anterior reconstruction have also been used in full-thickness defect reconstruction [101].

The sandwich technique is a single-stage procedure that fabricates a three-layer structure to restore the closing mechanics. This technique is centered on an orbicularis muscle flap that is then covered with an FTSG and posterior

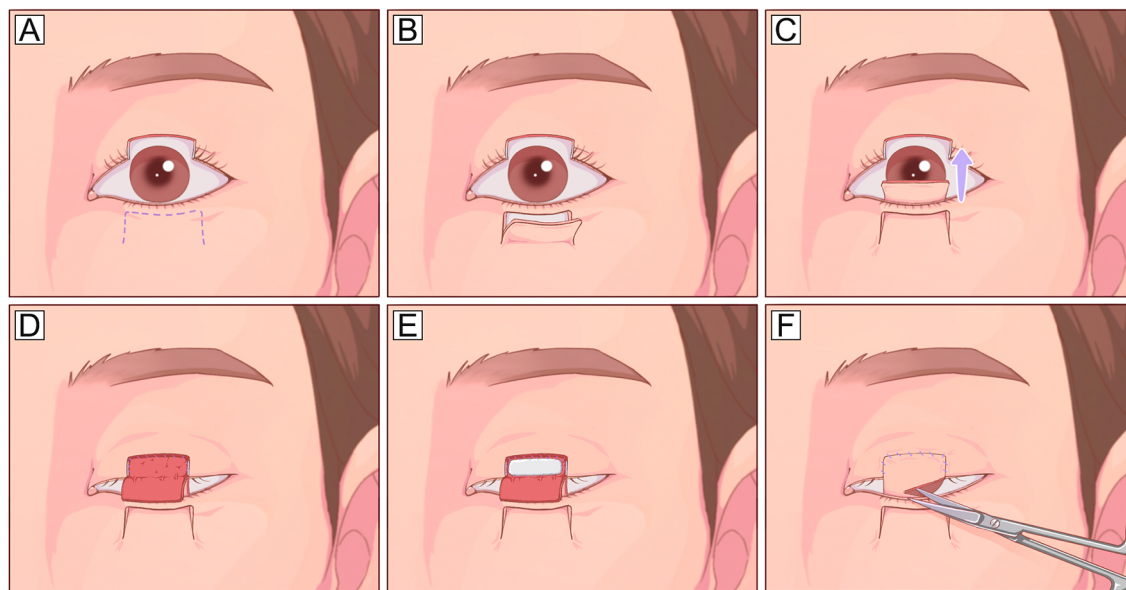


Fig. 12 Cutler-Bread flap. **A** A full-thickness defect involving the center upper eyelid and eyelid margin. The planned incision design is marked 4–5 mm below the lower eyelid margin to preserve the blood supply and stability of the lower eyelid. **B** A skin-muscle-conjunctiva flap is elevated on the lower eyelid. **C** The flap is tunneled underneath the undisturbed lower lid tarsus. **D** The flap is separated into a myocutaneous flap and a conjunctival flap,

and the conjunctiva flap is sutured along the defect to repair the conjunctiva defect. **E** An additional tarsal substitute (e.g., contralateral tarsus, cartilage, perichondrium) is applied to the conjunctival flap to repair the tarsal defect. The myocutaneous flap is covered onto the tarsal substitute and left attached for 2–4 weeks. **F** The pedicle is divided, and the remaining flap is replaced along the lower lid

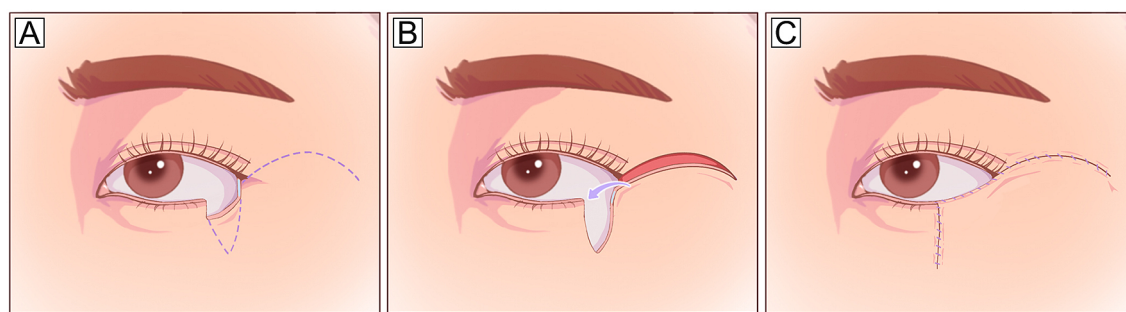


Fig. 13 Tenzel semicircular rotational flap. **A** A large full-thickness defect involving the lateral lower eyelid and eyelid margin. The planned flap incision is designed in a semicircular fashion from the lateral edge of the defect out toward the lateral eyebrow line. **B** The flap is initially undermined in the orbicularis muscle plane within the orbital rim and later along the subcutaneous plane beyond the orbital rim. A canthotomy of the upper limb of the

lateral canthus is selectively performed. **C** The remaining lid along the semicircular myocutaneous flap is rotated medially for primary closure of the defect. The myocutaneous flap is sutured to the lateral edge of the tarsus and secured to the periosteum at the lateral orbital rim to reestablish the lateral canthal height. The lateral canthal height can be reestablished with suture fixation to the superolateral orbital rim periosteum

lamellar substitute [55]. When the residual orbicularis muscle is insufficient, a frontalis

muscle flap can be used as the center of the “sandwich” instead, and the motor function of

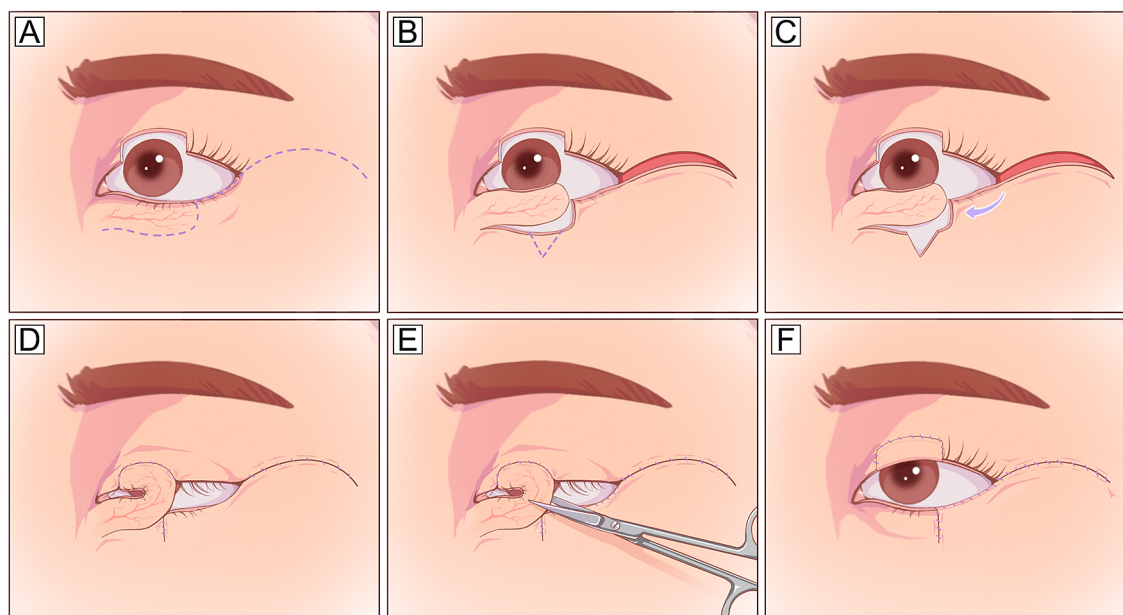


Fig. 14 Mustarde lower eyelid sharing flap. **A** A full-thickness defect involving the center upper eyelid and eyelid margin. Planned incision design for a lower eyelid sharing flap and a lateral Tenzel rotational flap. **B** The lower eyelid sharing flap is dissected from the center portion of the lower eyelid and based on a medial pedicle.

Simultaneously, the Tenzel flap is elevated, and a triangle-shaped tissue is planned for removal before the medial rotation of the Tenzel flap. **C** The Tenzel flap is rotated medially to repair the donor eyelid. **D** The lower eyelid flap is rotated superiorly to repair the upper eyelid defect. **E, F** The flap is divided after 2–4 weeks

the eyelid can also be restored to a certain extent [102]. In addition, tissue fabrication techniques have been applied for fabricating composite grafts for complex eyelid defect reconstruction, such as a chondromucosal-auricular graft [103], chondrocutaneous-myocutaneous composite graft [61], two-layer skin-cartilage unit [104], three-layer skin-cartilage-mucosal unit [105, 106], or skin-tendon-mucosal unit [45].

DISCUSSION AND FUTURE PERSPECTIVES

Clinical Thinking is Critical for Eyelid Defect Diagnosis and Treatment

Reconstruction of eyelid defects requires critical clinical thinking and integration of many different surgical techniques to achieve the most functional and aesthetic outcome. Before

planning, making an accurate and clear diagnosis for defects based on physical examination is a prerequisite for successful treatment. First, etiological diagnoses are made. Etiological diagnoses are the causes of defects such as trauma, burns, infection, or tumors. This information is beneficial for understanding the mechanism of defects and forming a general impression of the patient's condition. The second is functional diagnoses. Making functional diagnoses involves searching for the dysfunction on the affected eyelid and evaluating the severity of the dysfunction, such as ectropion, entropion, retraction, ptosis, or movement disorder. These eyelid dysfunctions are the purpose of surgical treatment. Finally, anatomical and pathological diagnoses are made. Making anatomical or pathological diagnoses involves trying to determine the mechanisms of eyelid dysfunction at the anatomical or pathological level. For instance, for defects caused by trauma or burn scars, intensive attention should be

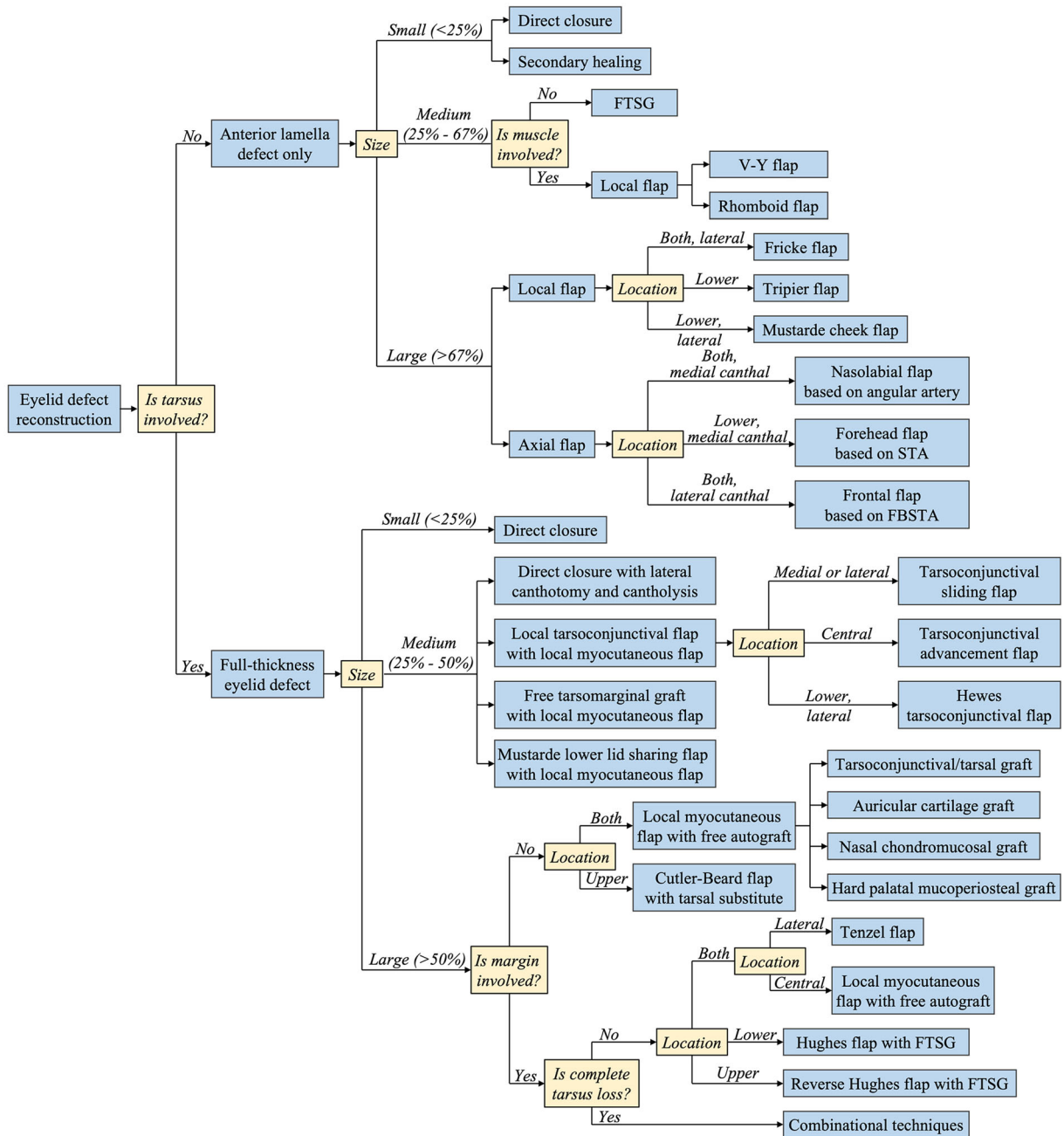


Fig. 15 Schematic overview of eyelid defect reconstruction strategies for different conditions. *FTSG* full-thickness skin graft

given to examining which structures are affected, how large the defect is, and what conditions the surrounding tissues are; for defects caused by infection or tumors, the pathological type and possible infiltration depth of the lesion should be considered. The combination of these three diagnostic approaches enables plastic

surgeons to make sound decisions. We recommend a three-step strategy for eyelid defect diagnosis and reconstruction technique selection: the thickness, size, and location. Figure 15 illustrates a decision tree outlining the options discussed in this review.

Tarsus Tissue Engineering: Transforming from the Replacement Strategy to a Regenerative Strategy

In general, surgical techniques for anterior lamellar reconstruction can achieve adequate function and aesthetic restoration. However, great challenges remain in posterior lamellar reconstruction due to its unique properties and lack of ideal tissue substitutes, especially for the tarsus. Ideally, the conjunctival substitute should be a stable, thin, and elastic construct. In addition, the construct should support efficient epithelial repopulation, stratification, and even goblet cell differentiation to fully mimic the structure and function of native conjunctiva [107, 108]. Autologous tarsoconjunctival grafts or flaps are the gold standard option for posterior lamellar reconstruction but are limited by donor sources. Although various free autografts have been used to replace the damaged tarsus in clinical conditions, none of them can solve the mechanical strength and lubricant problems. Current techniques for eyelid reconstruction, especially posterior lamellar reconstruction, are a replacement strategy with limited functional and aesthetic reconstruction outcomes. Exploring a regenerative strategy for posterior lamellar reconstruction by following the principle of tissue engineering will be one of the breakthroughs in plastic and reconstructive surgery in the future. The growing field of tissue engineering offers promising alternative solutions to this challenge.

Attempts have been made to use biomaterials for clinical posterior lamellar reconstruction. ADM, derived from human (AlloDerm[®], BellaDerm[®]) [82, 109–111], porcine (Endurage[®]) [112–114], or bovine (Surgimen[®]) [114, 115] dermis, provides a convenient off-the-shelf alternative for tarsus substitutes due to its good histocompatibility and lower inflammation. They are flexible but sturdy flat sheets of cross-linked collagen matrixes with a basement membrane surface and a dermis surface. However, graft contraction, resorption, and inflammatory responses appear to be the main disadvantages limiting its widespread clinical use [116, 117]. The use of biopolymeric materials, which are relatively biocompatible, rigid,

and moldable, may overcome these limitations. Currently, porous high-density PE (Medpor[®]) has been clinically used for improving lower eyelid retraction [118]. However, high complication rates, including implant exposure, poor stability, skin contour abnormalities, and unexplained pain, make it sparingly used in eyelid surgery. However, the use of biomaterial substitutes has achieved limited clinical outcomes, opening a door for developing biological substitutes for tarsus, even tarsoconjunctiva. In the future, tissue engineering will advance toward engineering a compound construct consisting of both a layer of dense tissue with certain mechanical strength for tarsus reconstruction and a layer of smooth tissue with lubrication and secretion function for palpebral conjunctiva reconstruction. Such a construct should not only replace the damaged tissue but also take part in tissue regeneration by the transplanted cells and scaffolds.

CONCLUSIONS

Comprehensively, when planning an optimal strategy for complex eyelid defect reconstruction, surgeons should have a thorough understanding of eyelid anatomy, follow the reconstructive ladder principles, and consider the defect characteristics. Surgical techniques provide various solutions for anterior lamellar reconstruction and usually result in excellent eyelid functional and aesthetic outcomes. However, posterior lamellar reconstruction remains a challenge and often requires the integration of many different techniques to achieve the most functional and aesthetic outcome.

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Data Availability. The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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